

On the Recovery Stress of a $\text{Ni}_{50.3}\text{Ti}_{29.7}\text{Hf}_{20}$ High Temperature Shape Memory Alloy

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Motivation and objectives

- **Recovery stress** obtained during a dimensionally constrained, martensitic phase transformation.
- Where is it used?
 - Fastening and joining
 - Rock splitting
 - Safety/release mechanisms
 - Medical devices (stents)
 - reinforced composites/ concrete confinement
 - Shape setting procedures
 - Jamming loads
- Goals: Investigate the stress recovery capability of a precipitation strengthened, $\text{Ni}_{50.3}\text{Ti}_{29.7}\text{Hf}_{20}$ (at.%) high temperature SMA in uniaxial tension and compression.



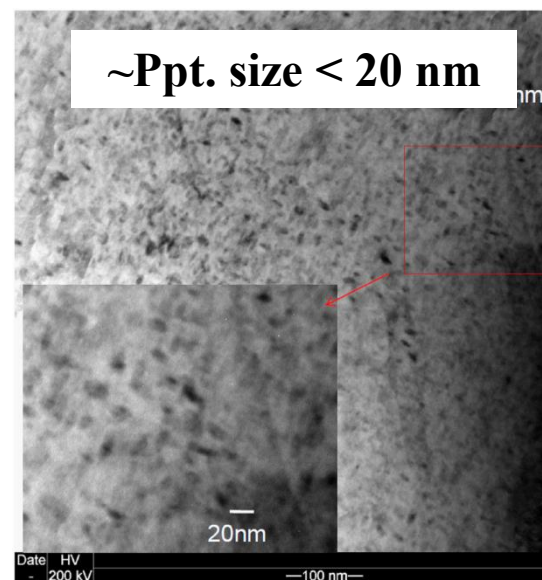
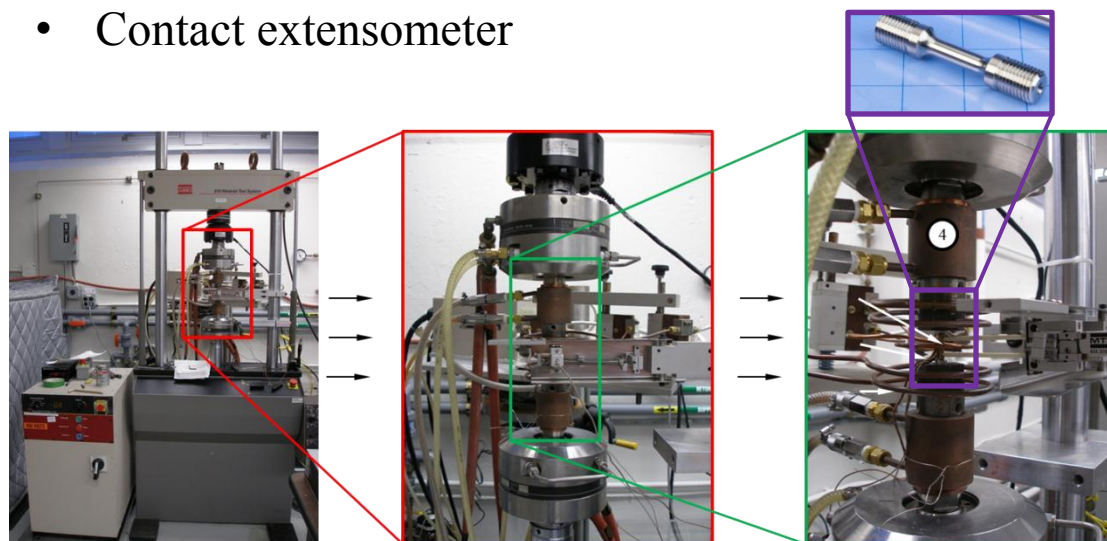
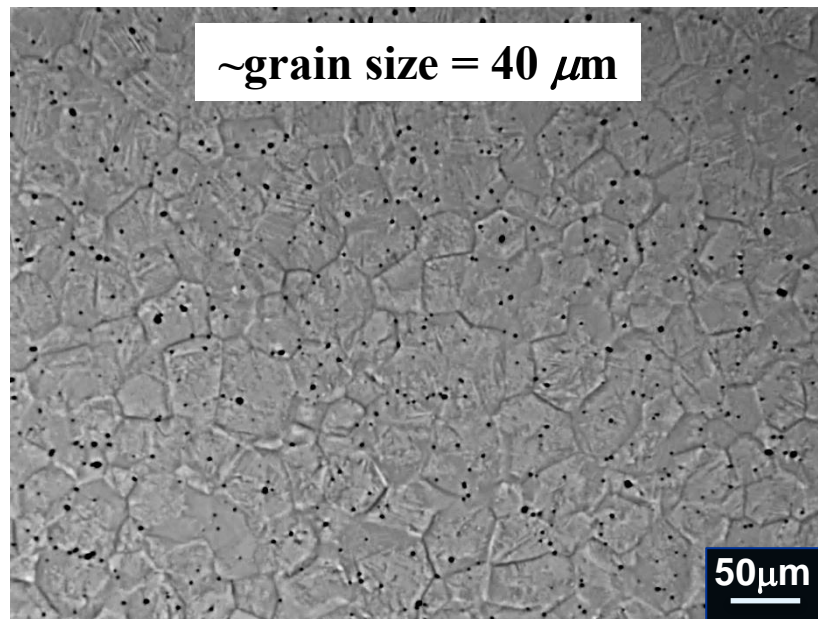
Ni_{50.3}Ti_{29.7}Hf₂₀ processing and testing

Processing:

- Induction melted (~60lbs)
- Homogenized at 1050 °C for 72 h
- Extruded to rods (~0.4" in diameter) at 900 °C (7:1)
- Machined to form (dogbone, cylinders...)
- Aged 550 °C/3hrs/AC (Argon)

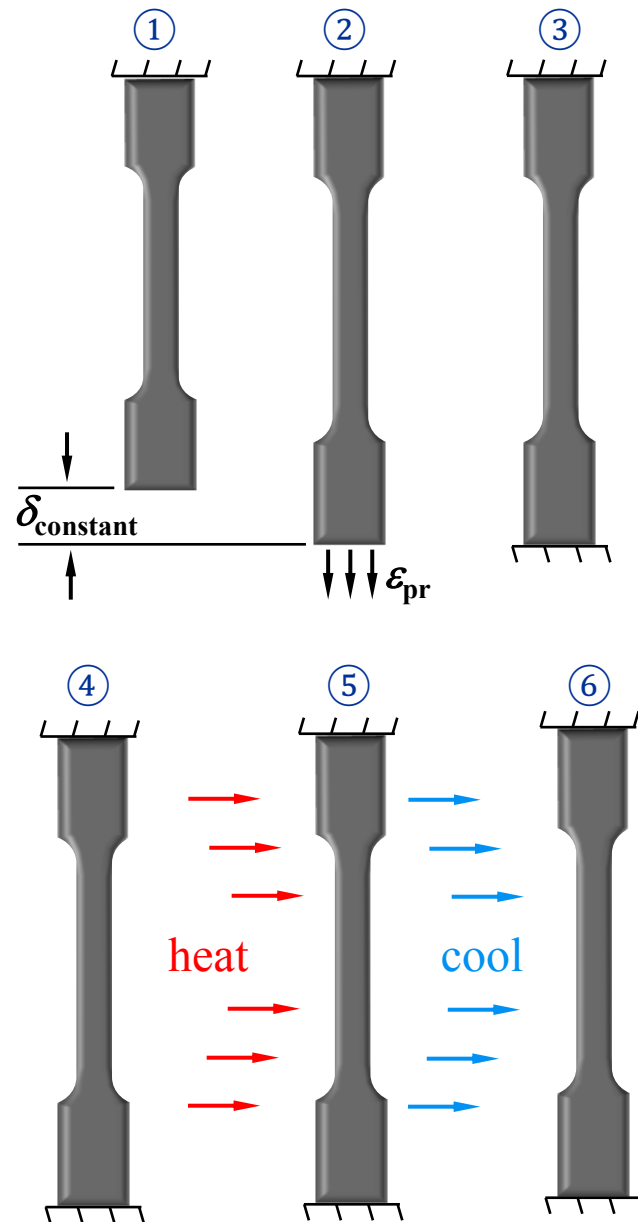
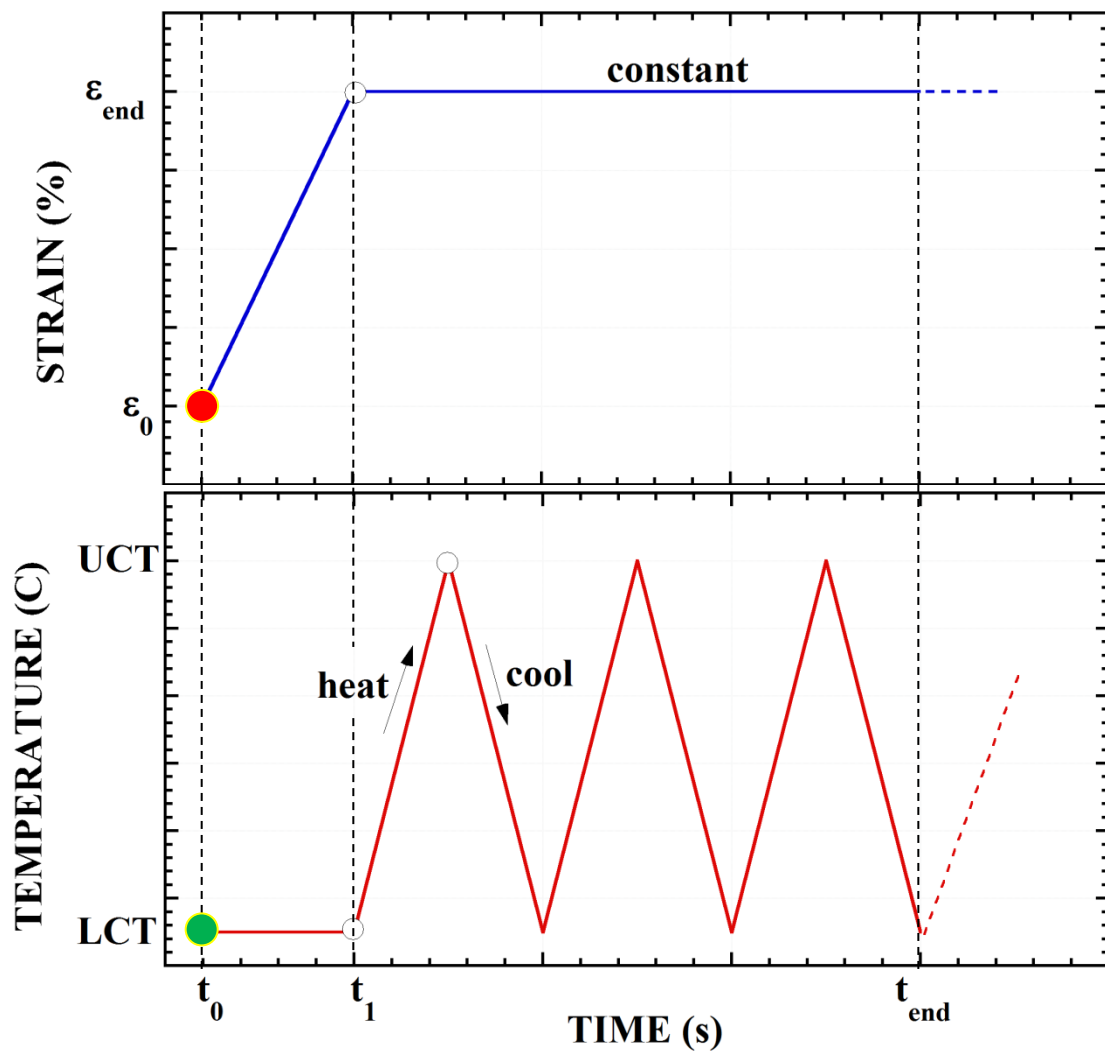
Testing

- Servohydraulic frame
- Induction heating
- Contact extensometer





Constant-strain thermal cycling procedure

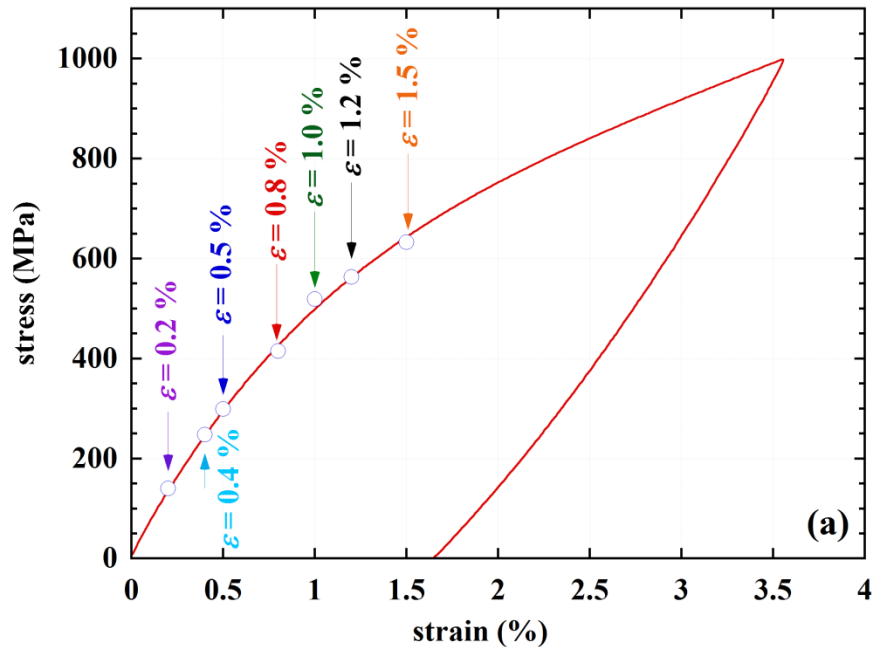




Training I: Isothermal loading within the fully reversible region (*No plastic deformation*)

Tension

$T = 25^\circ\text{C}$



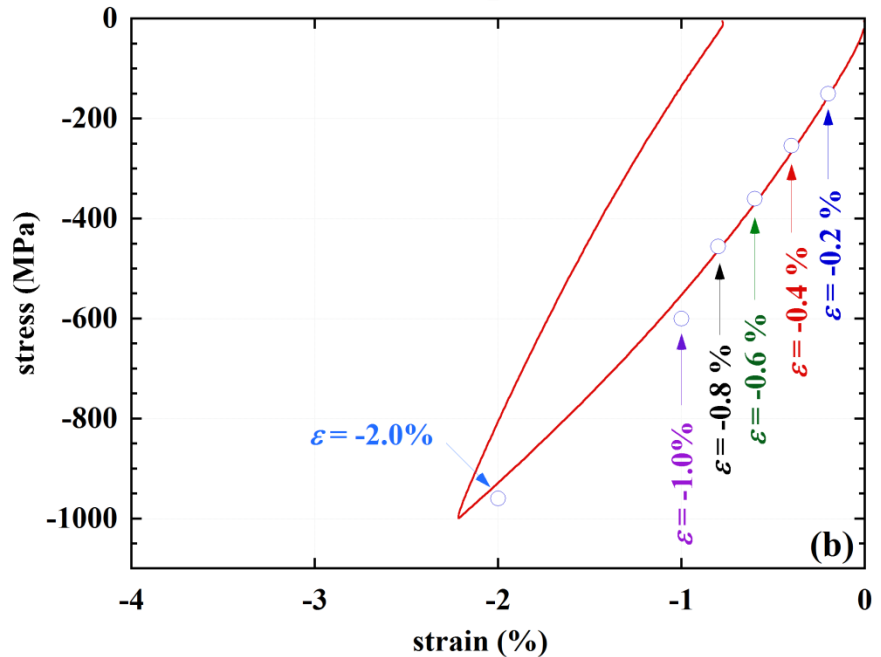
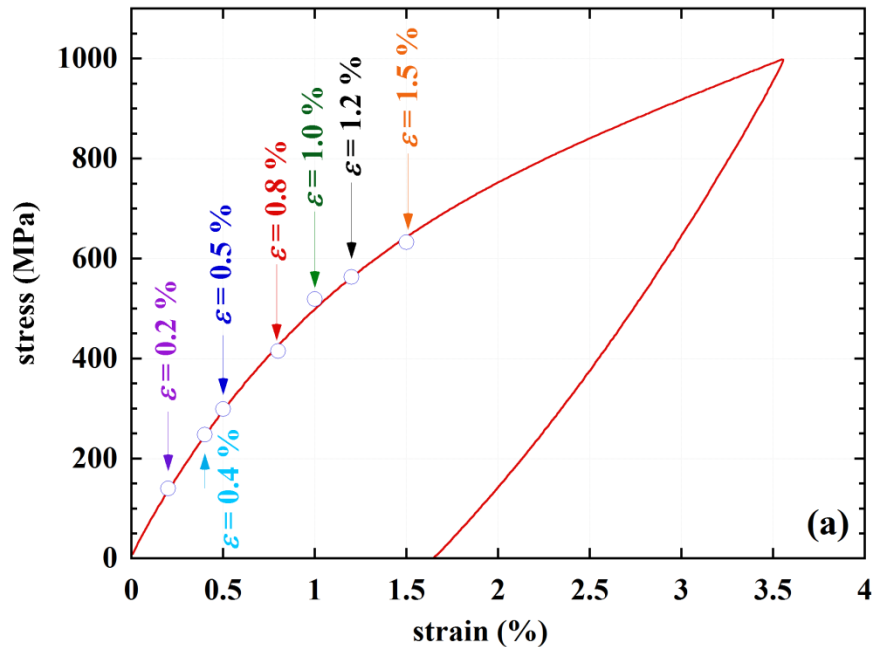


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Compression



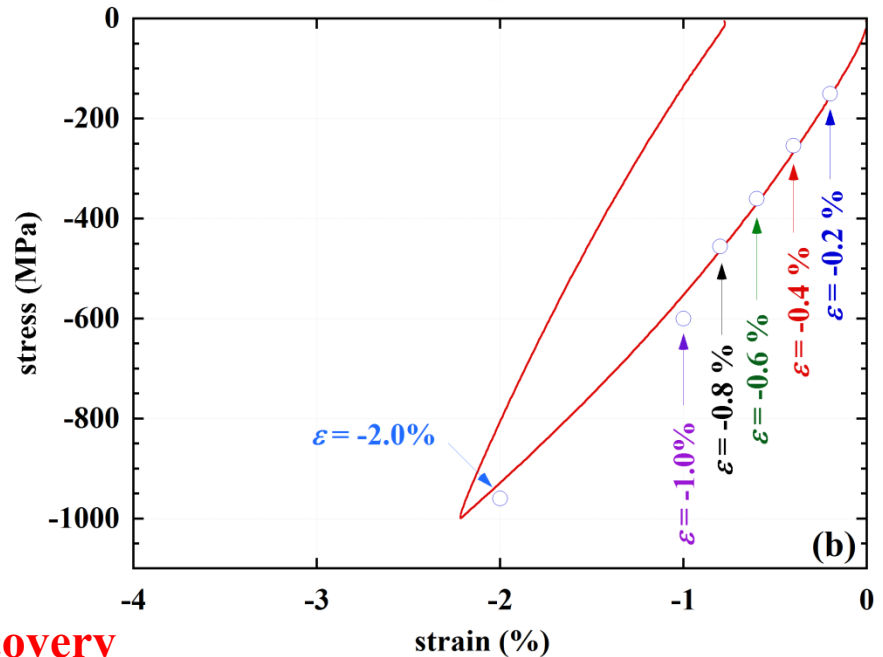
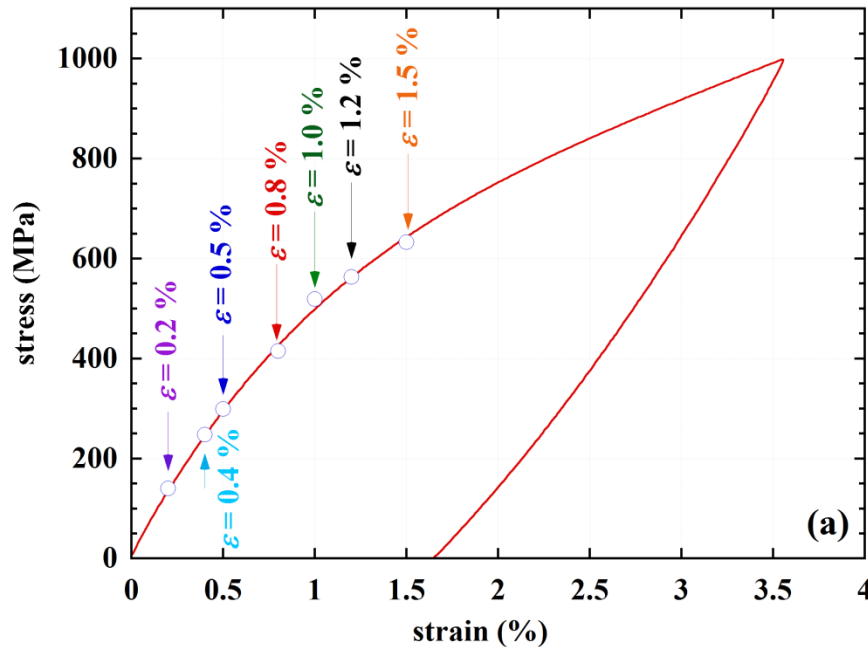


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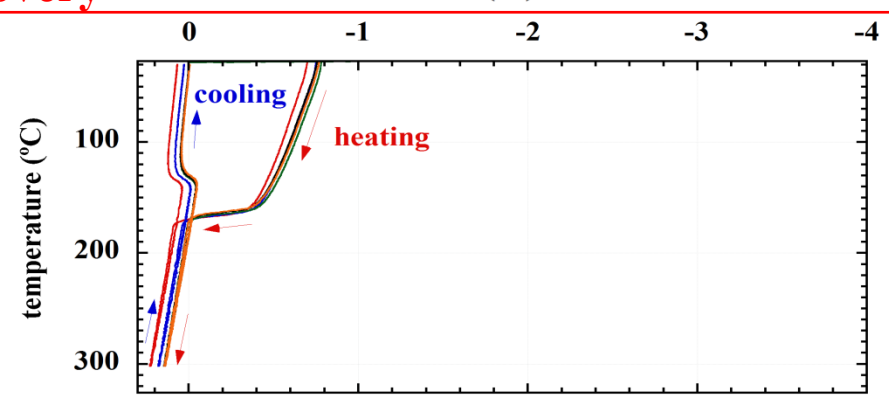
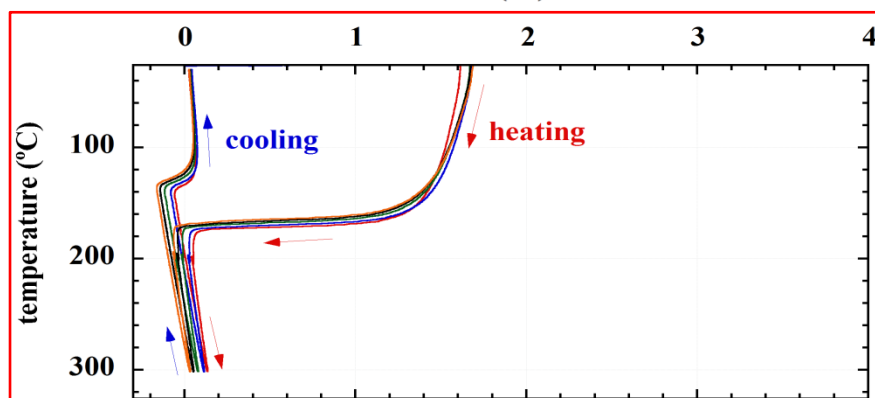
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Compression



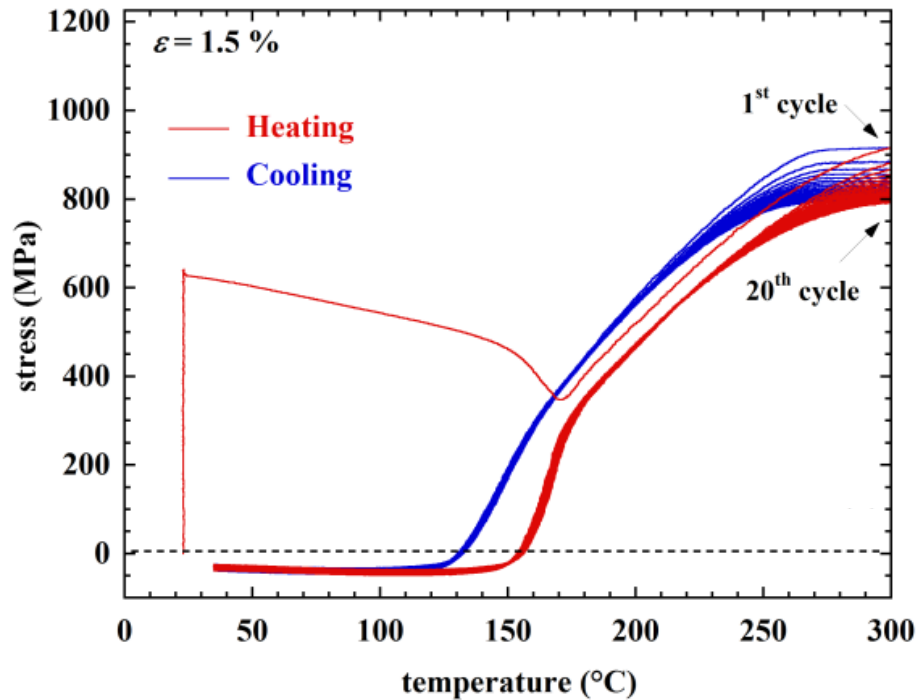
Recovery



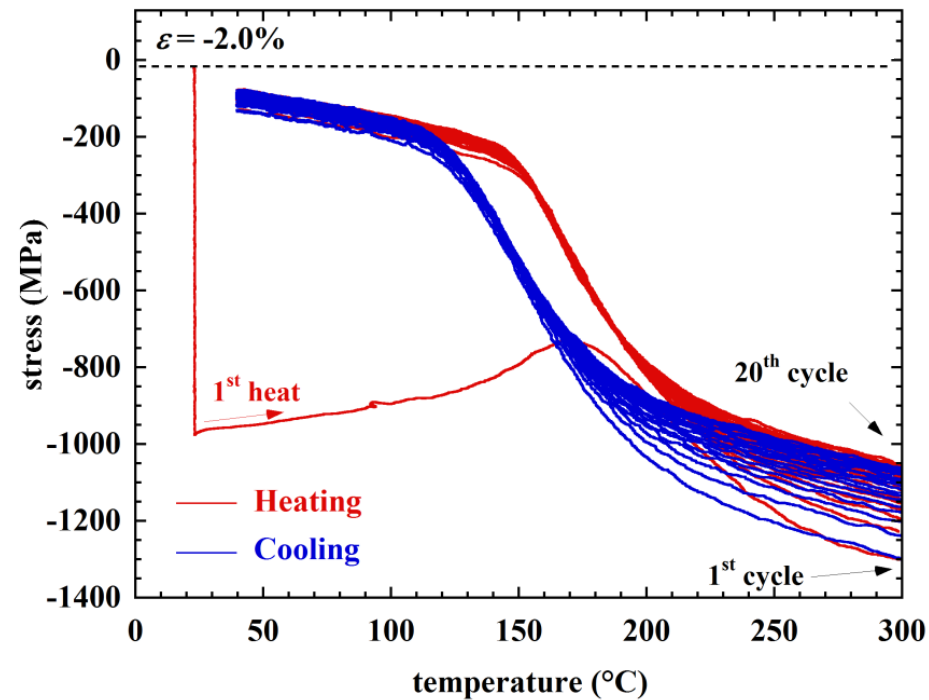


Constant-strain thermal cycling: Resultant recovery stress

Tension



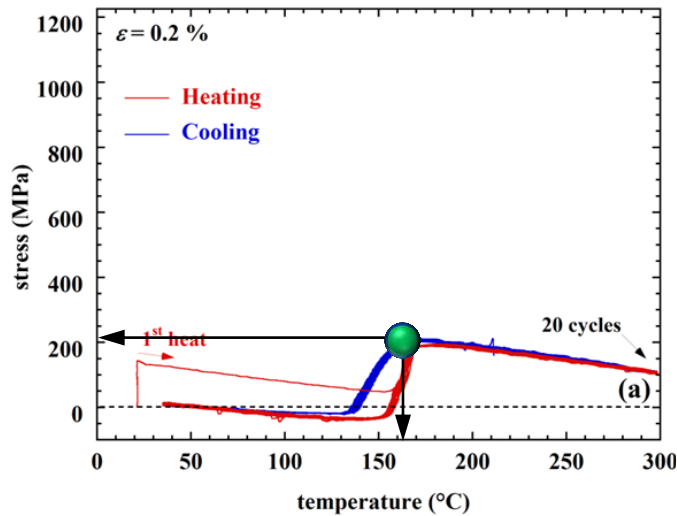
Compression



- Stress buildup on heating
- Relaxed to zero or to a slightly compressive or tensile stress on cooling
- Thermal expansion contribution, against in tension, with in compression

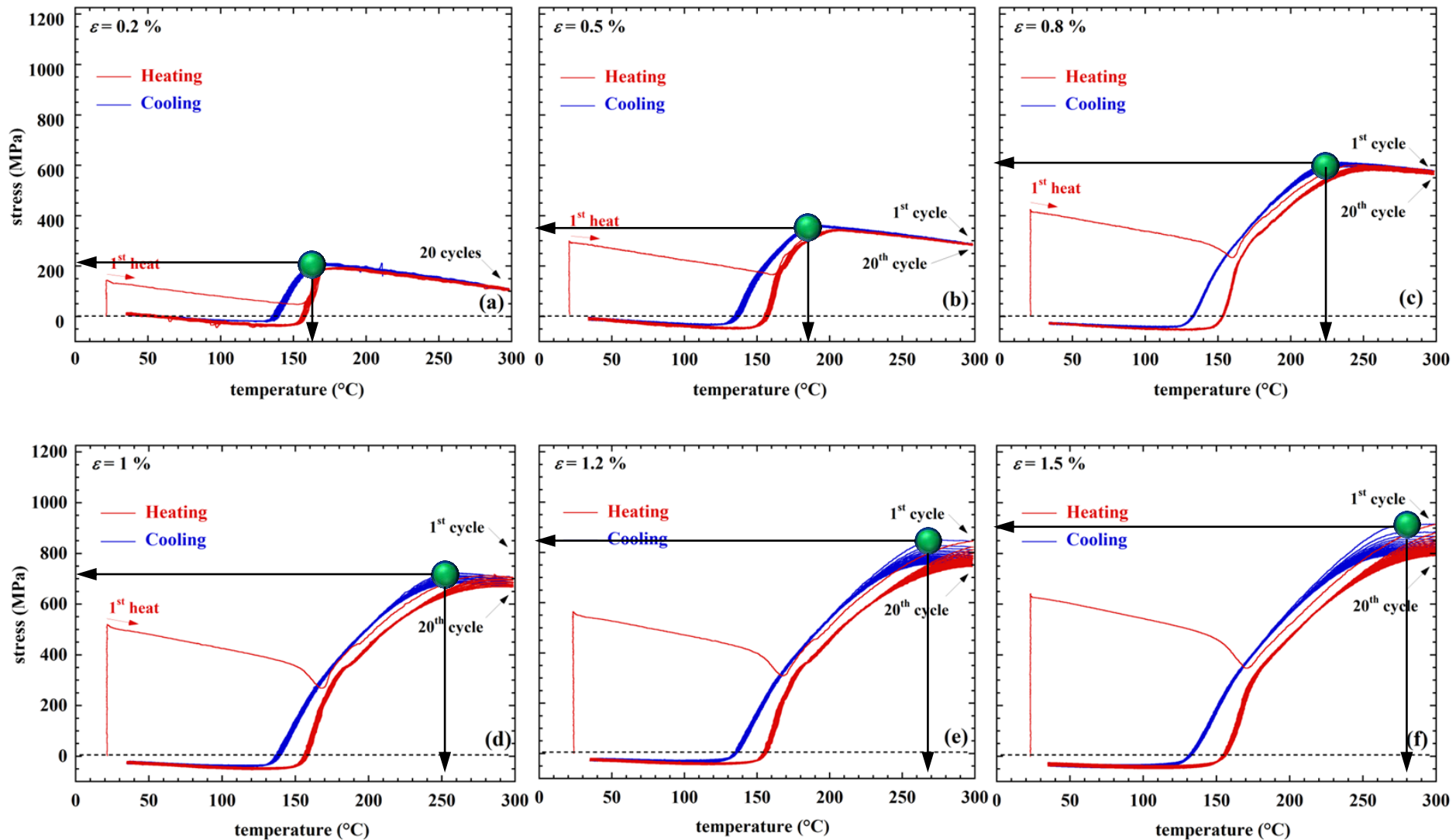


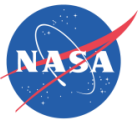
Constant-strain thermal cycling: Resultant recovery stress (**Tension**)



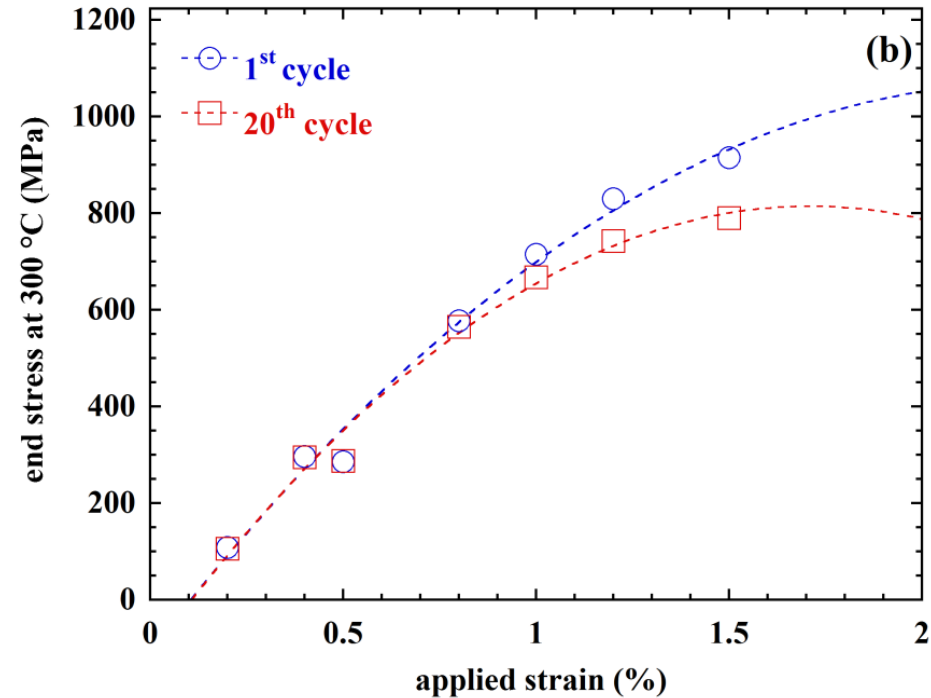
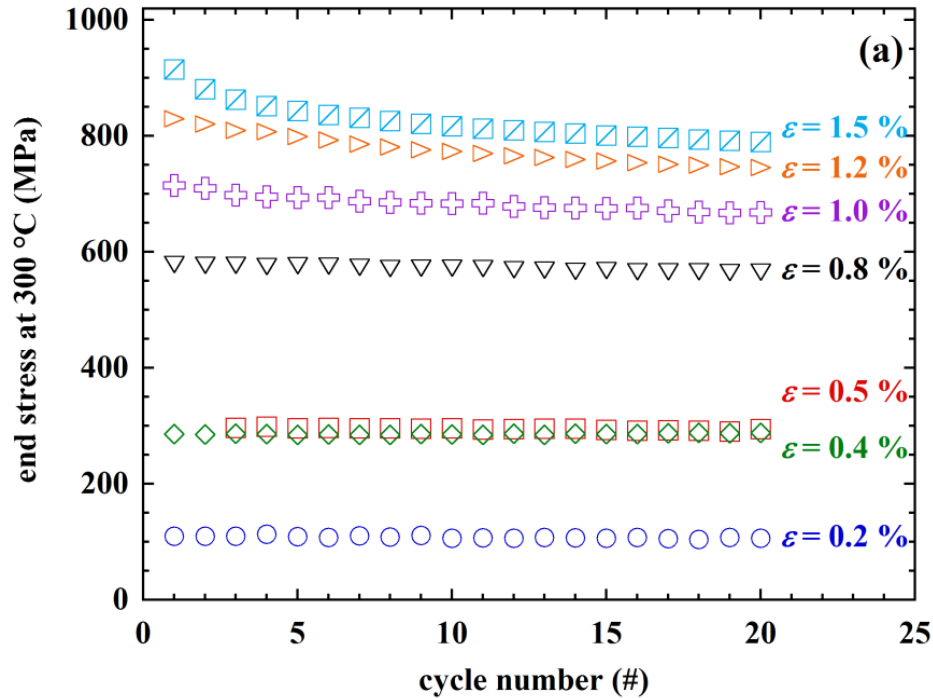


Constant-strain thermal cycling: Resultant recovery stress (**Tension**)





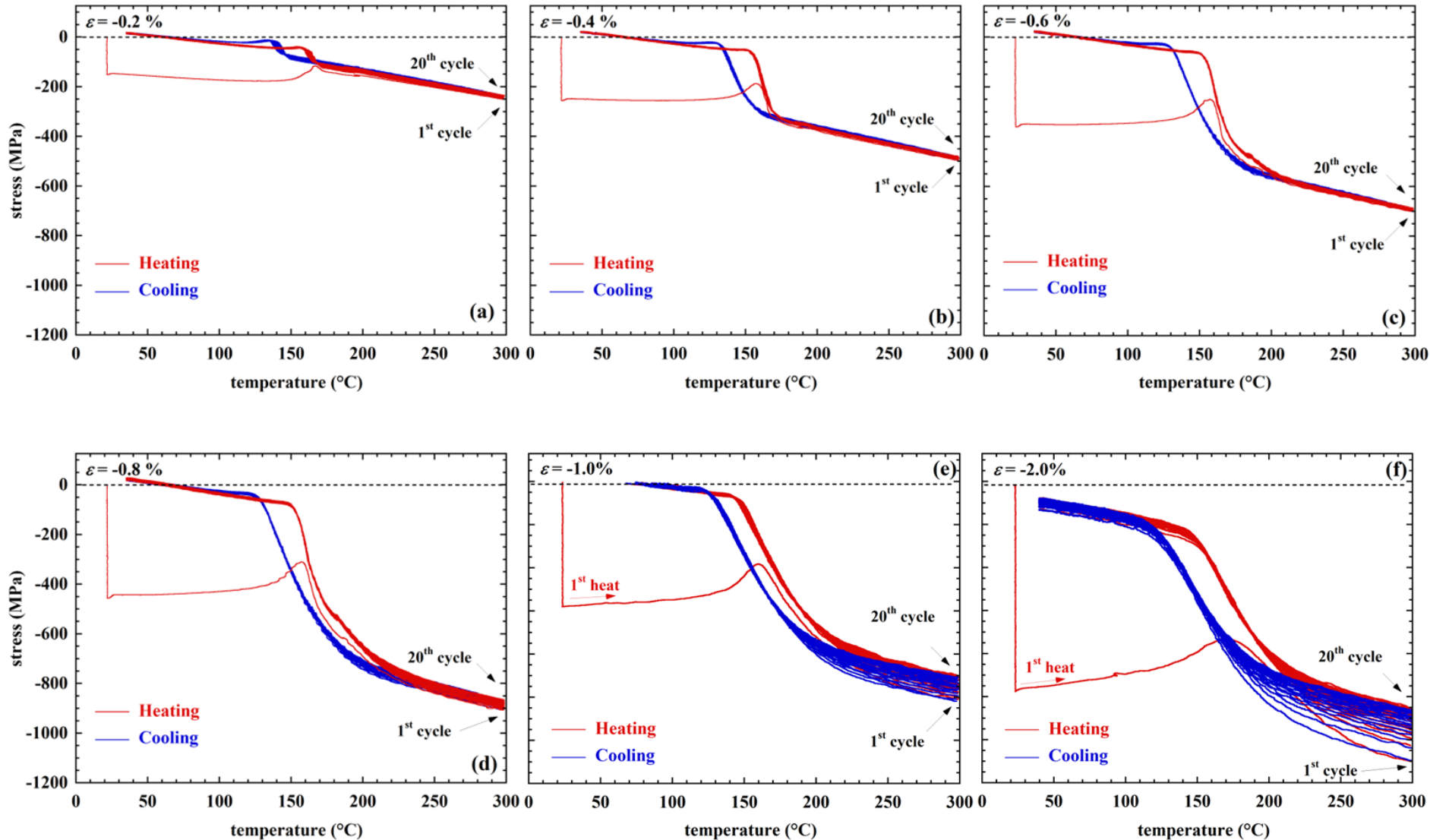
Constant-strain thermal cycling: Resultant recovery stress (**Tension**)



- Stresses in excess of 1 GPa
- Stress evolution for pre-strains $> 1\%$ (yielding of B2 phase)

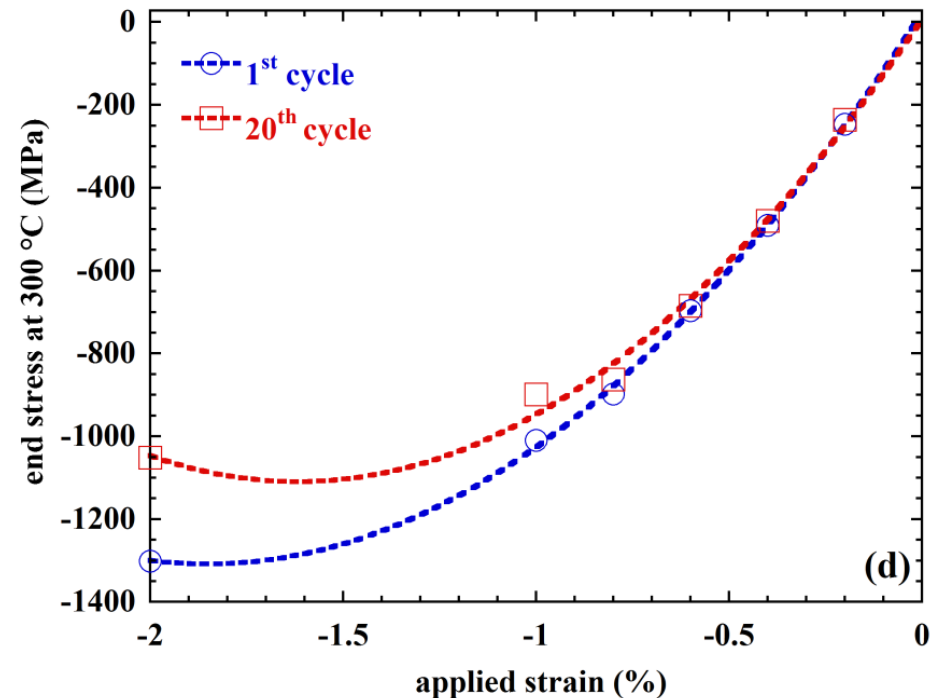
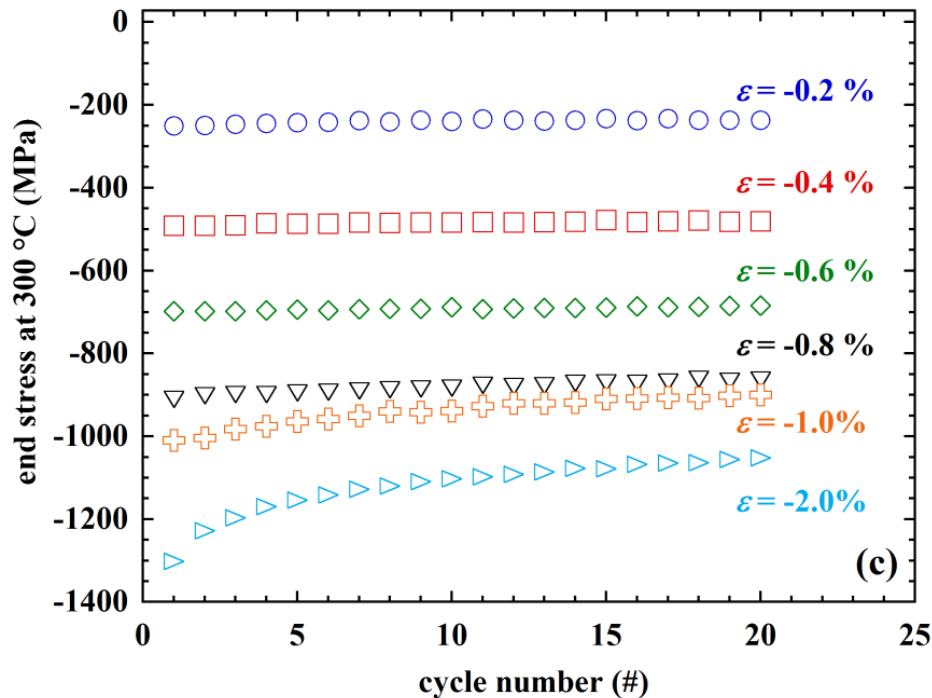


Constant-strain thermal cycling: Resultant recovery stress (**Compression**)





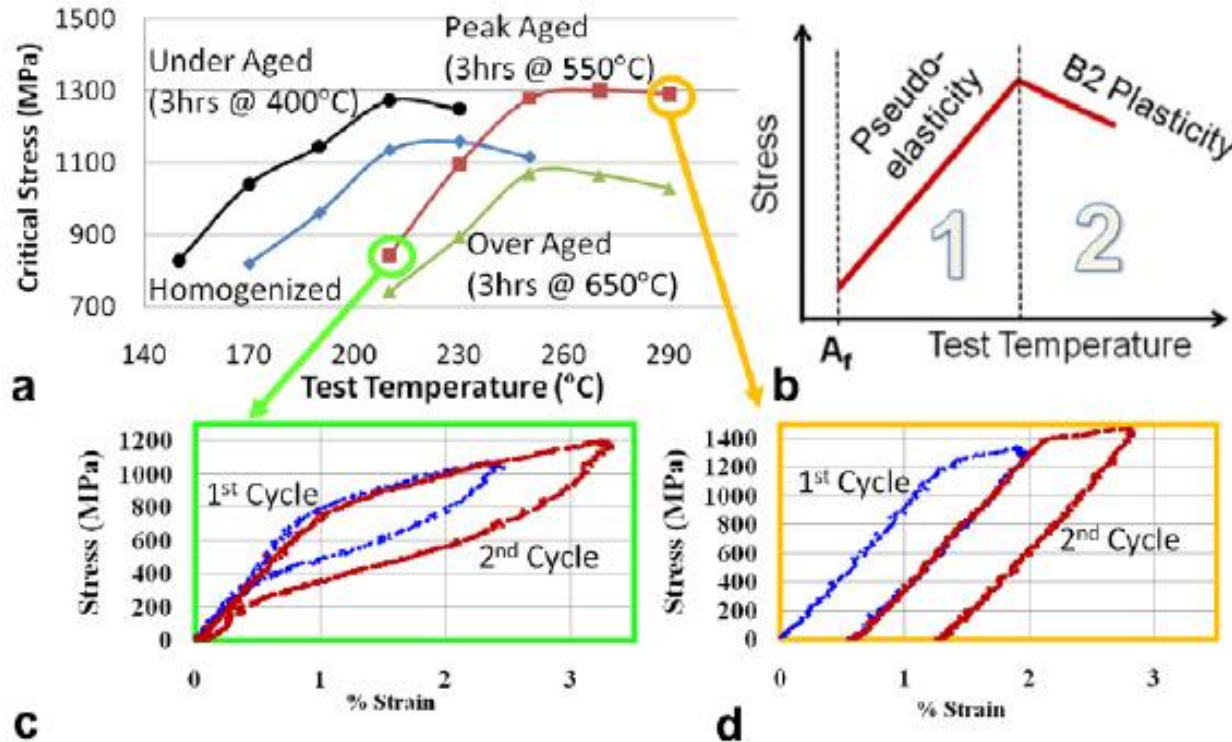
Constant-strain thermal cycling: Resultant recovery stress (**Compression**)



- Stresses of ~1.3 GPa
- Stress evolution for pre-strains $< -0.8\%$ (yielding of B2 phase + retained martensite +...)



Constant-strain thermal cycling: Resultant recovery stress (**Compression**)

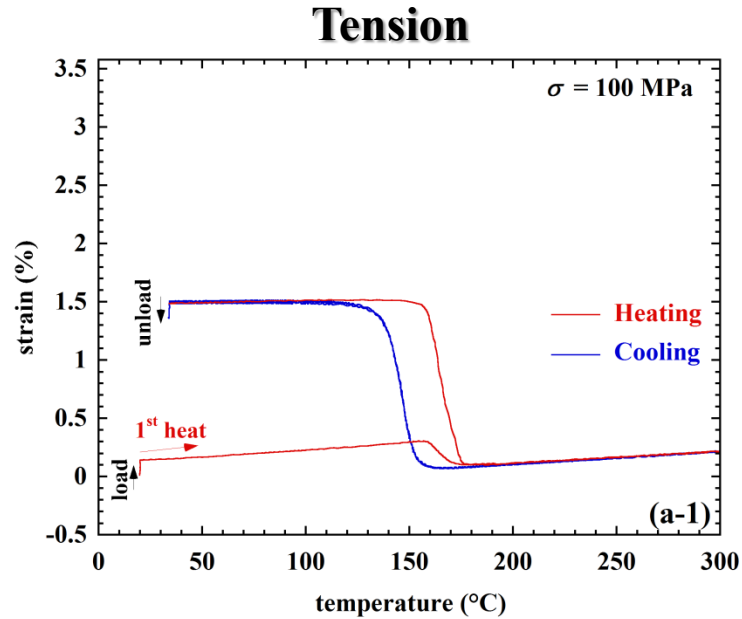


D.R. Coughlin et al. / Scripta Materialia 67 (2012) 112–115

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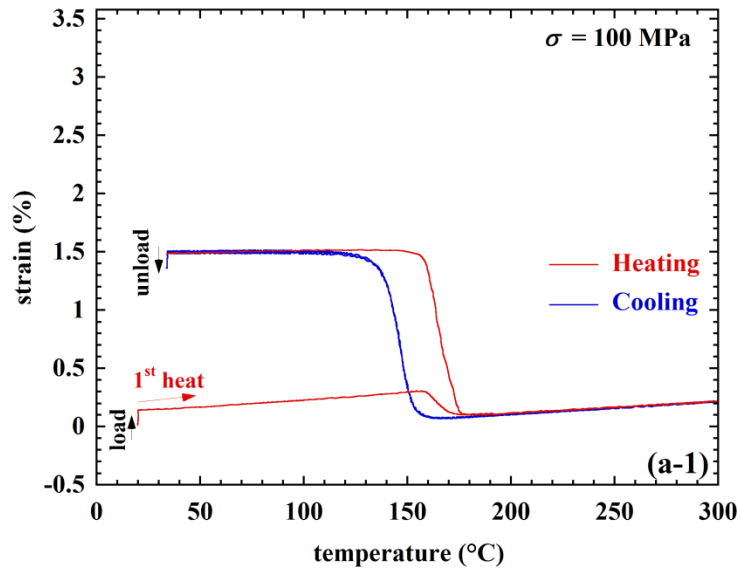
Training II: Constant-force thermal cycling (No residual strains)



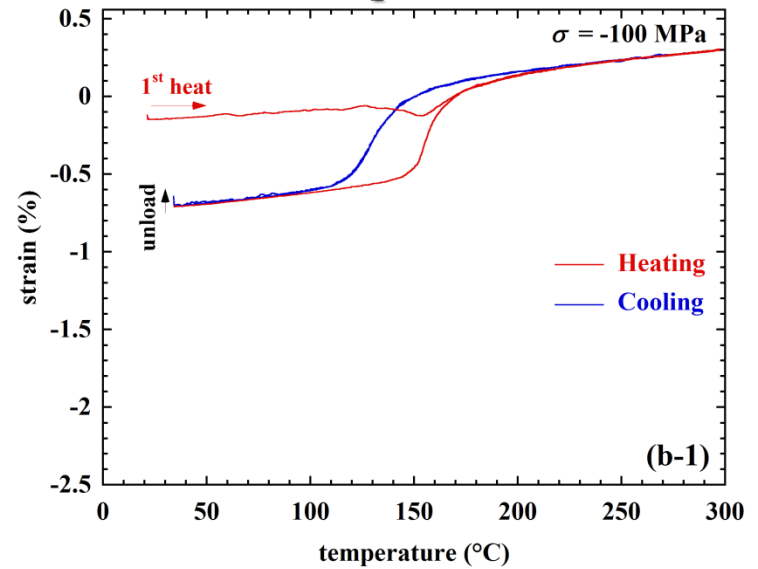


Training II: Constant-force thermal cycling (No residual strains)

Tension



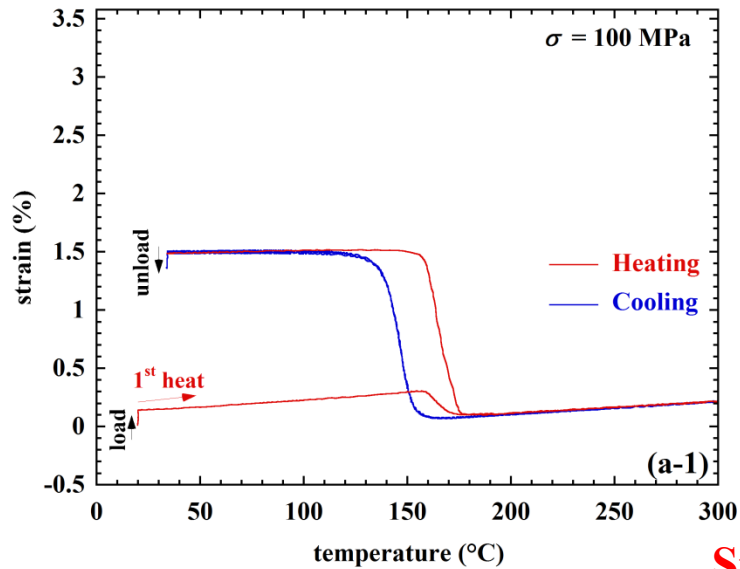
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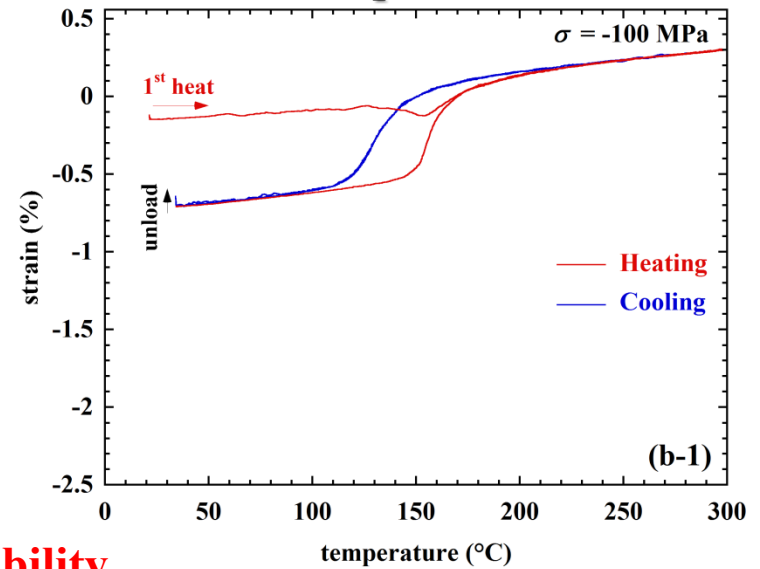


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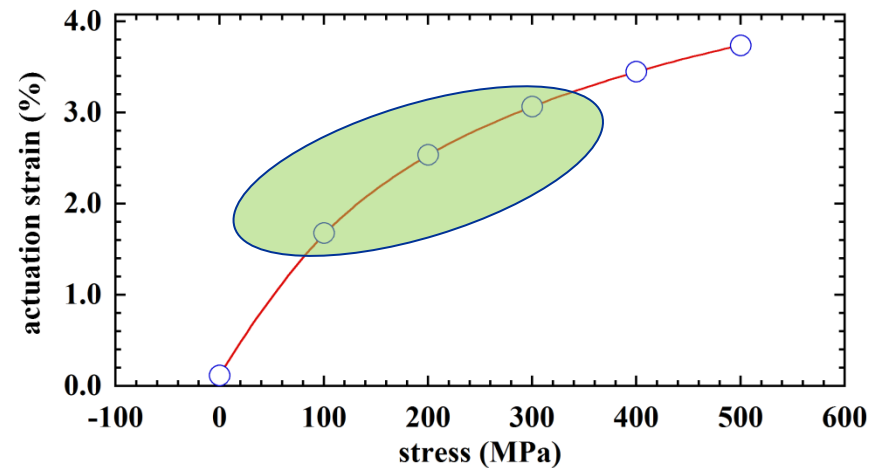
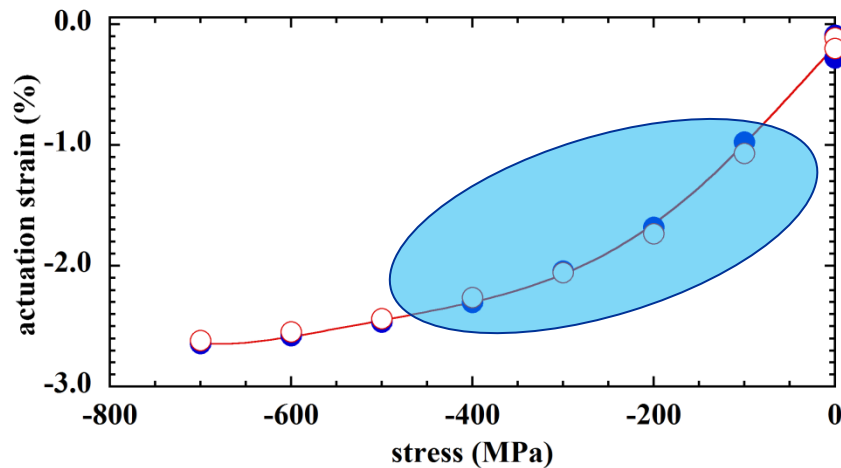
Tension



Compression



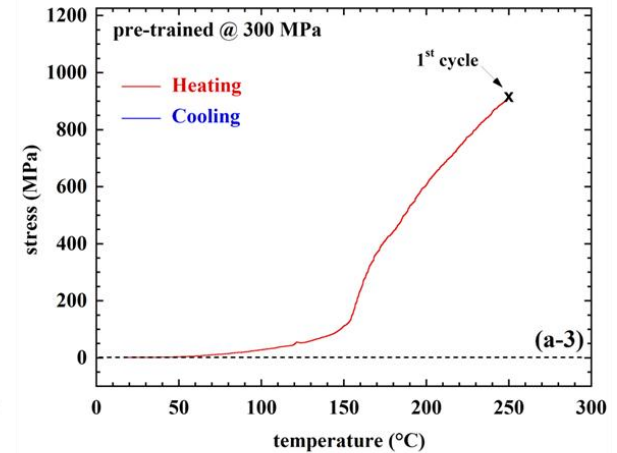
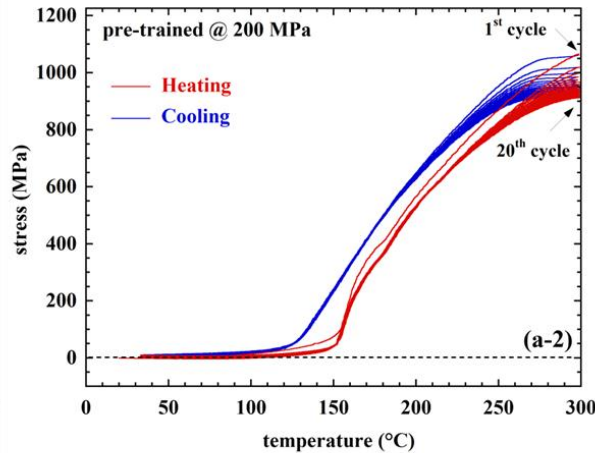
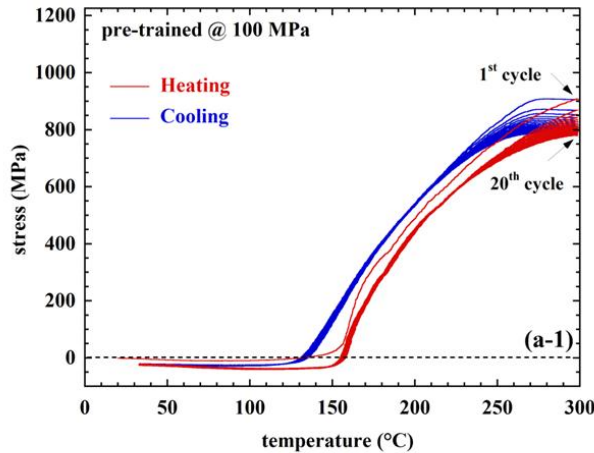
Strain capability



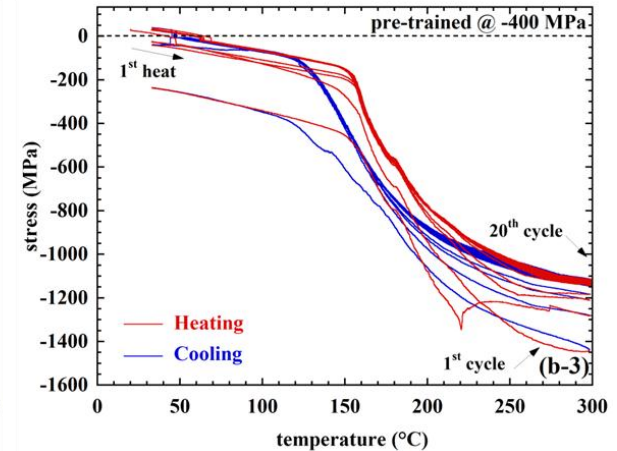
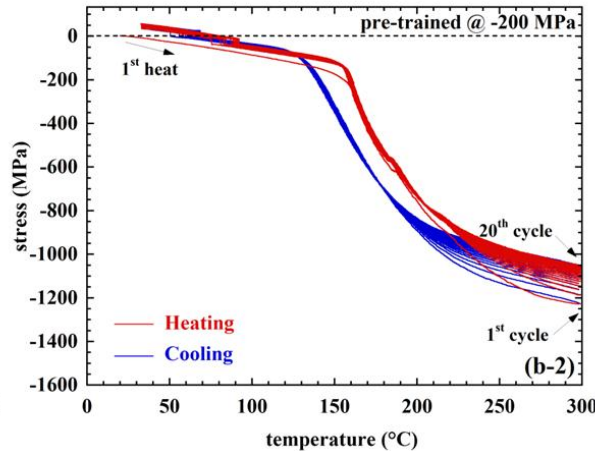
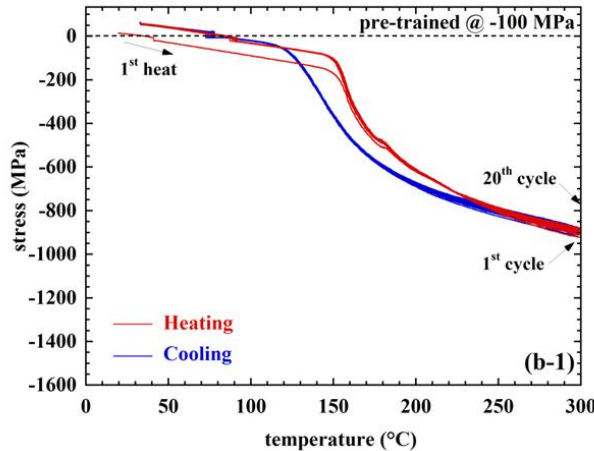


Constant-strain thermal cycling: Resultant recovery stress

Tension

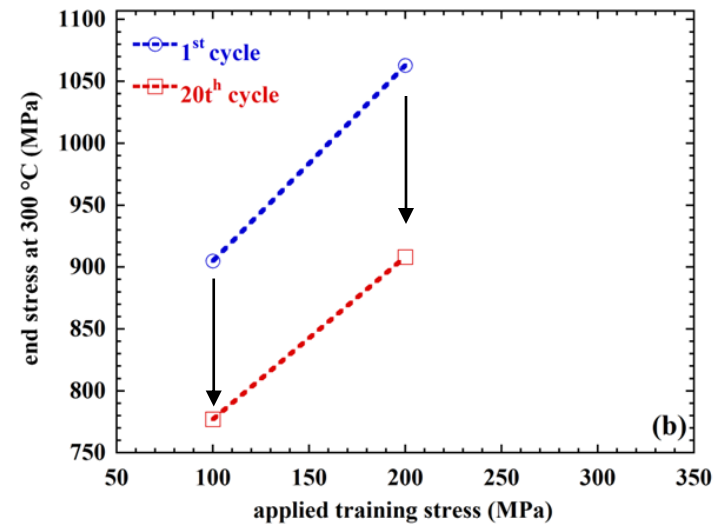
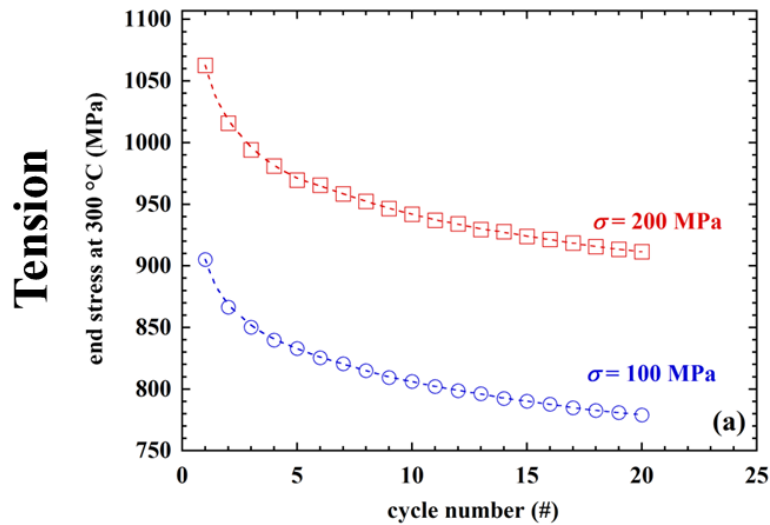


Compression





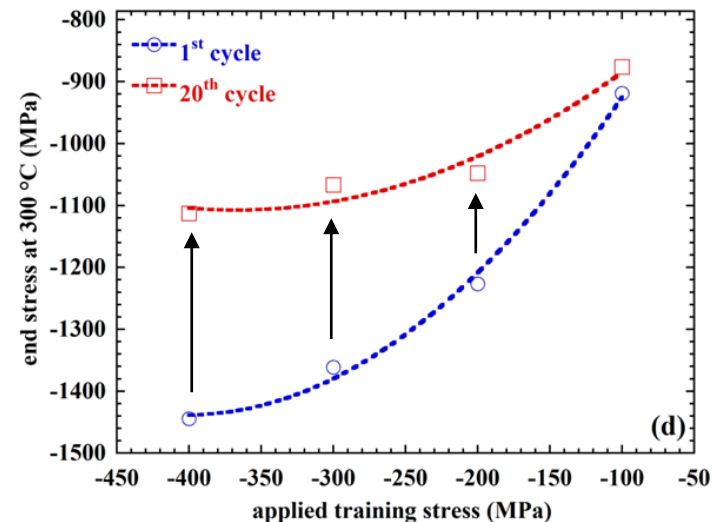
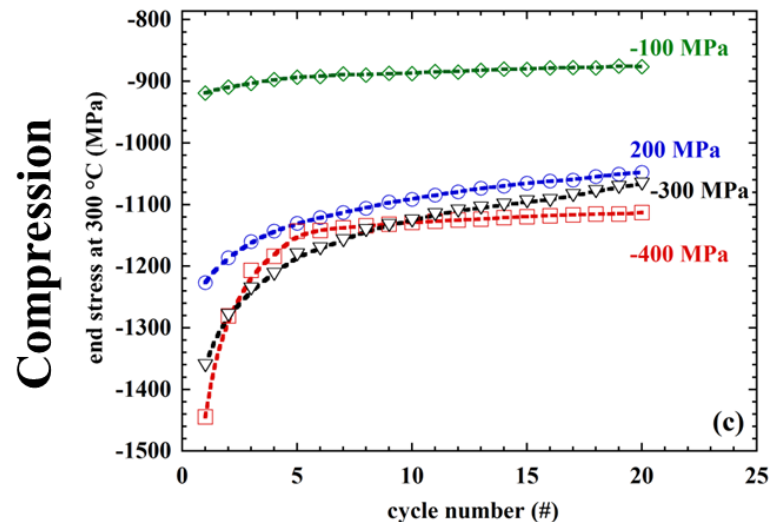
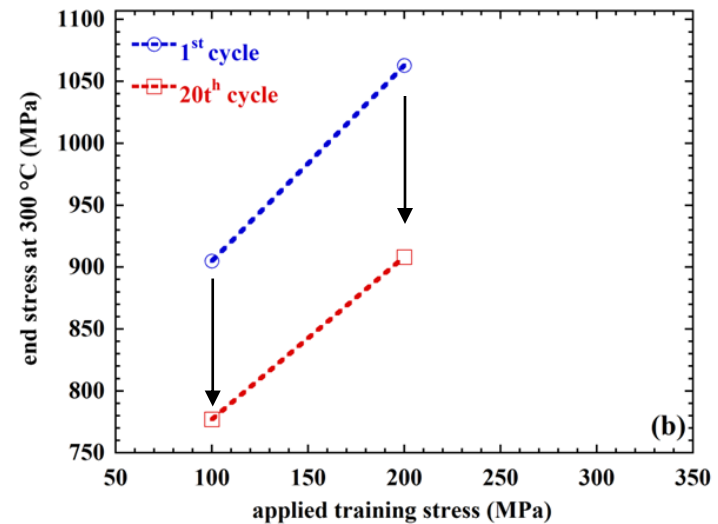
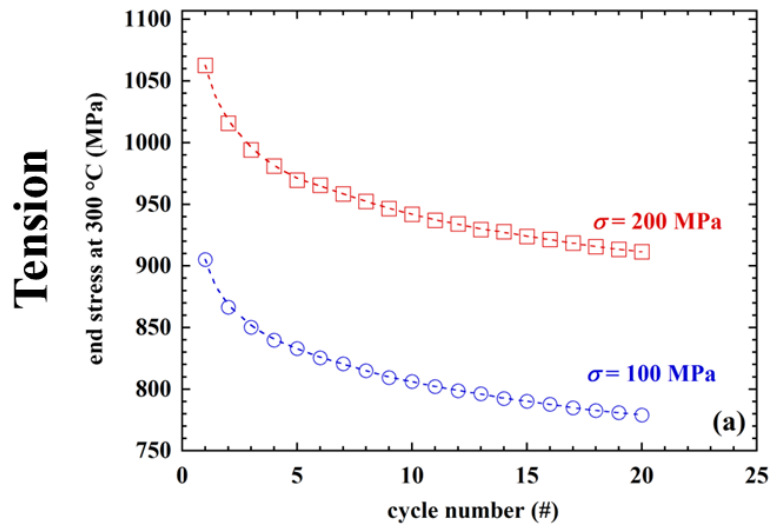
Constant-strain thermal cycling: Resultant recovery stress



- Stresses of ~1.0 GPa in tension



Constant-strain thermal cycling: Resultant recovery stress

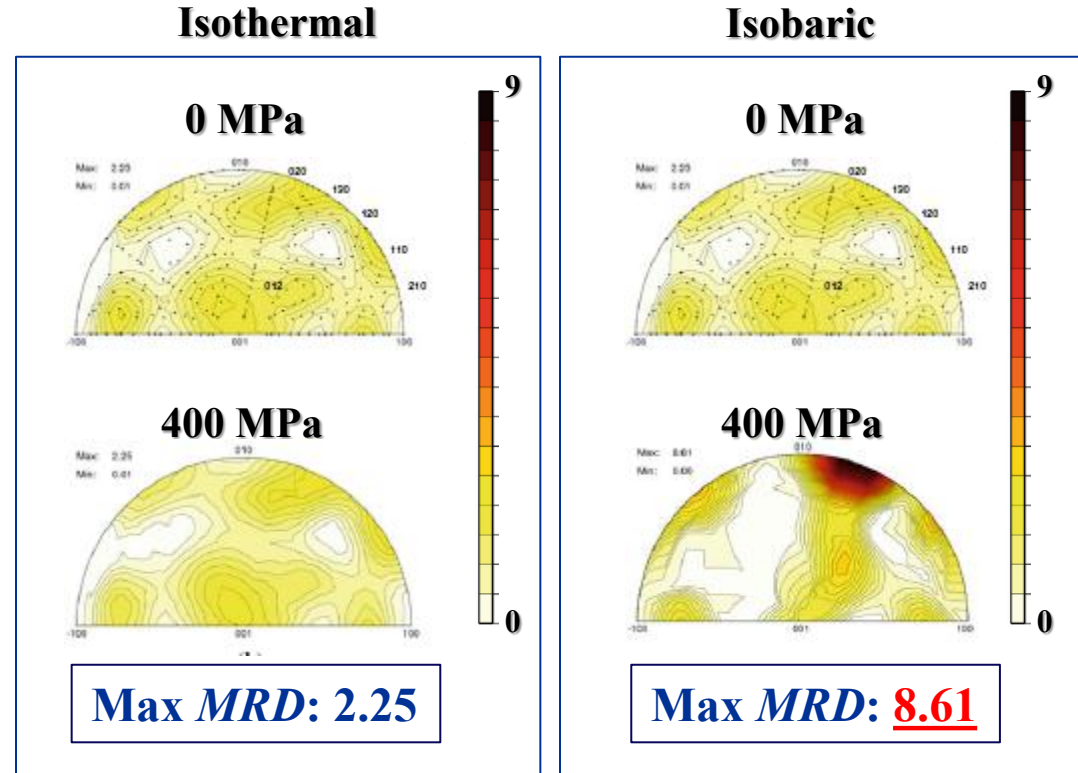


- Stresses in excess of ~1.5 GPa, saturation at ~1.1 GPa (in compression)



Training I (Isothermal) **vs.** Training II (Isobaric)

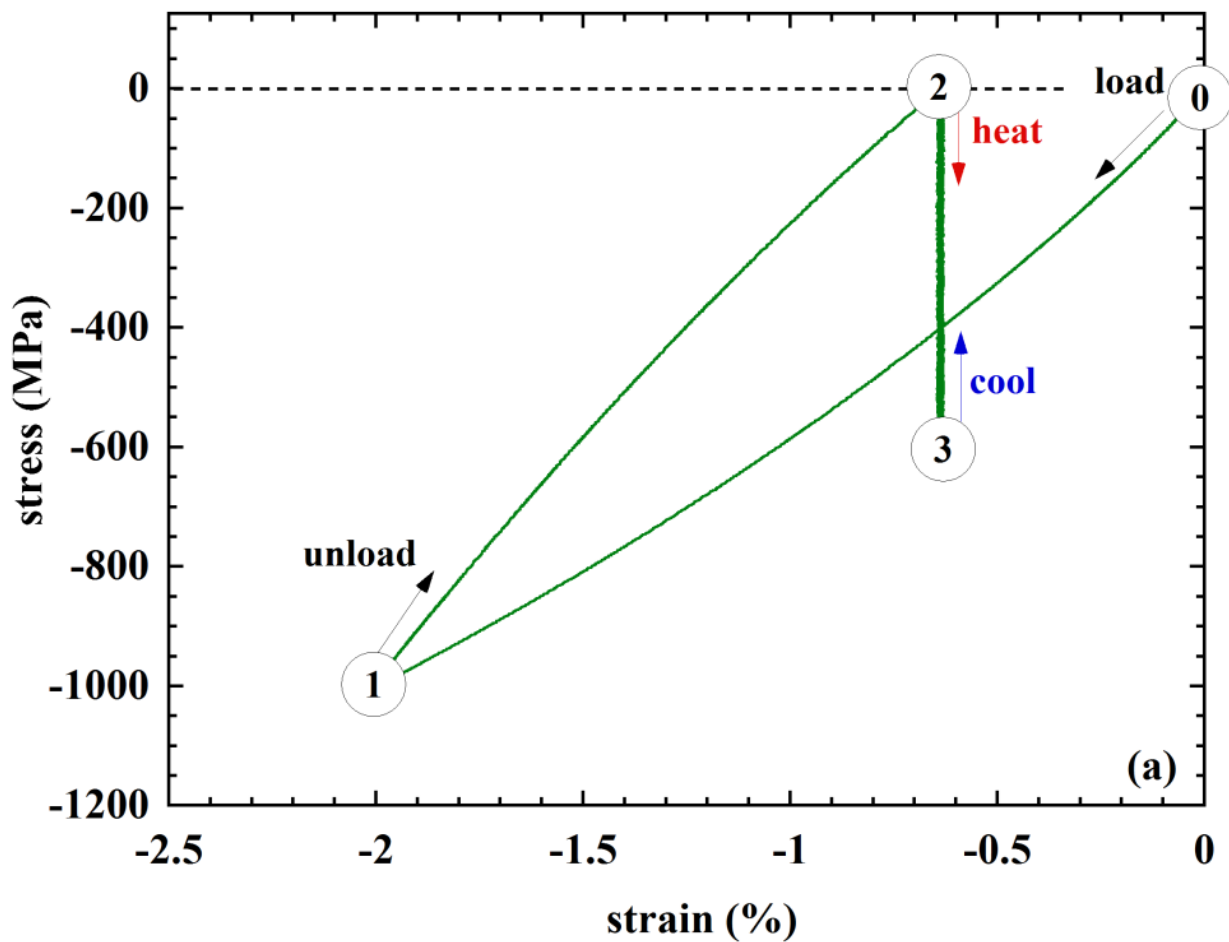
- Isothermal reorientation and detwinning (R&D) of the B19' is almost unnoticeable.
- Most R&D occurs on the 1st constant-strain cycle.
- Isobaric (R&D) occurs on the very first cycle.
- The majority of transformation occurred before the 1st constant-strain cycle.



O. Benafan, et al., *Metallurgical and Materials Transactions A*, 2012, 13A, p. 4539–52.



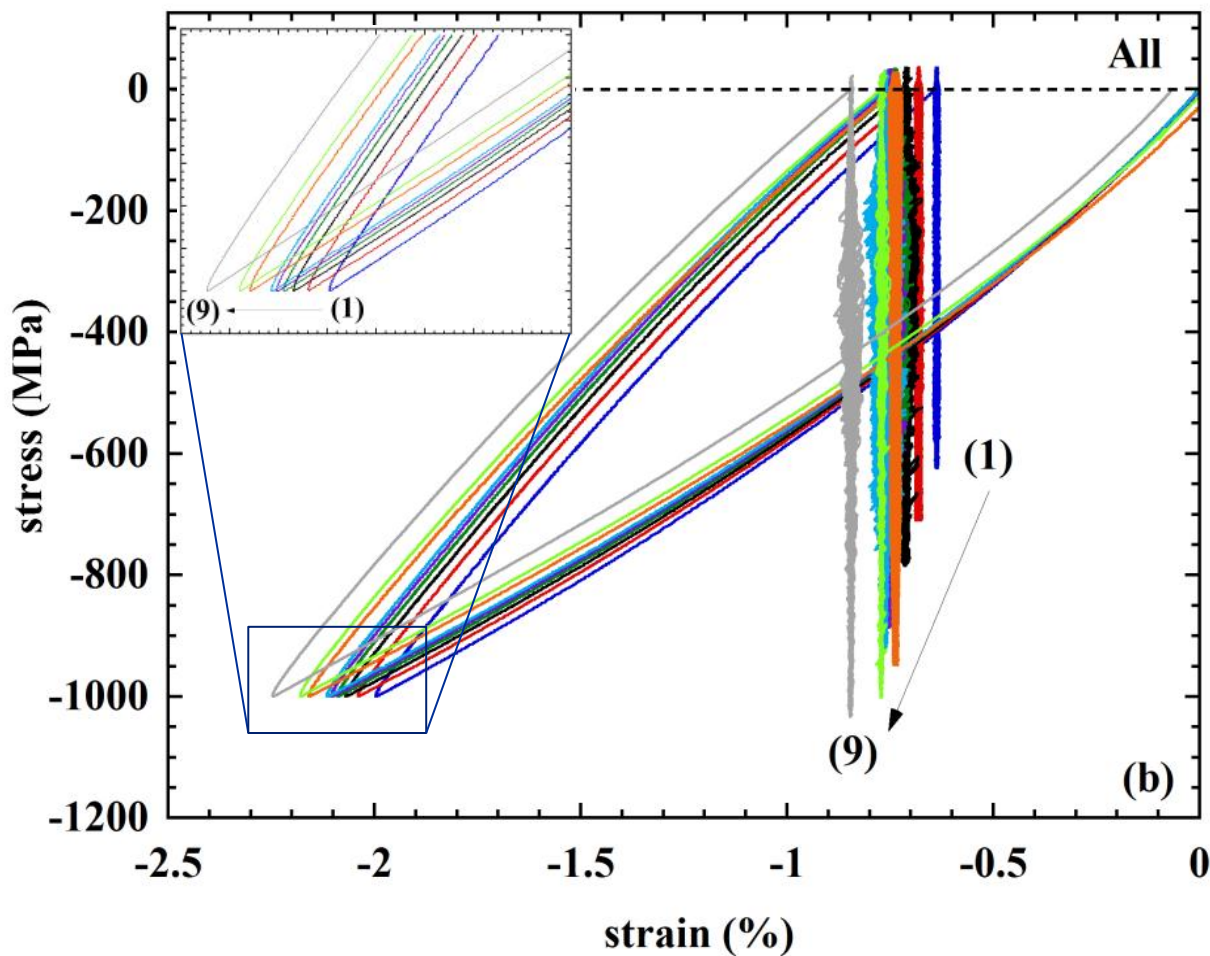
Training III: Cyclic isothermal deformation (load-unload)



1 sequence



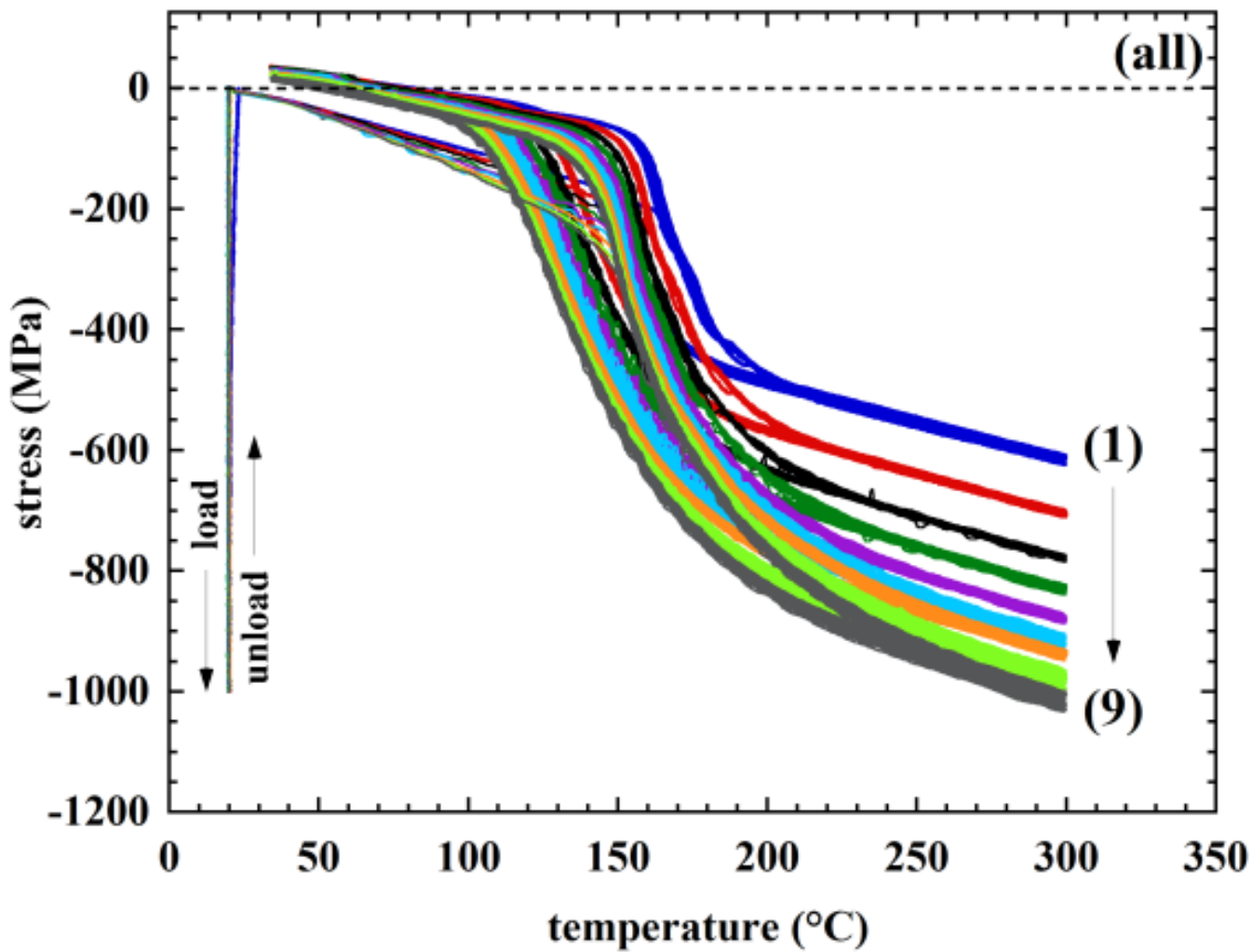
Training III: Cyclic isothermal deformation (load-unload)



9 sequences



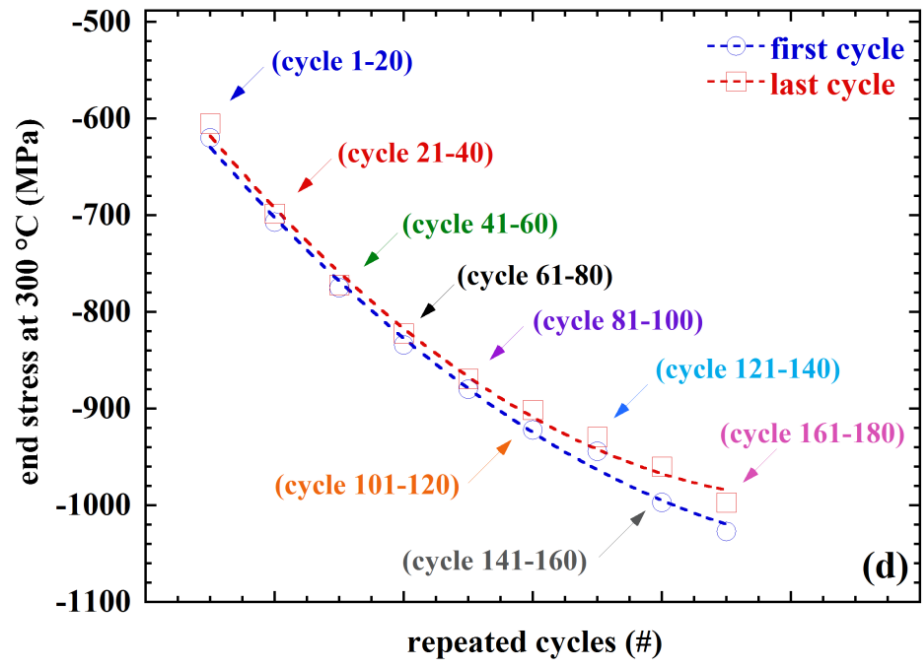
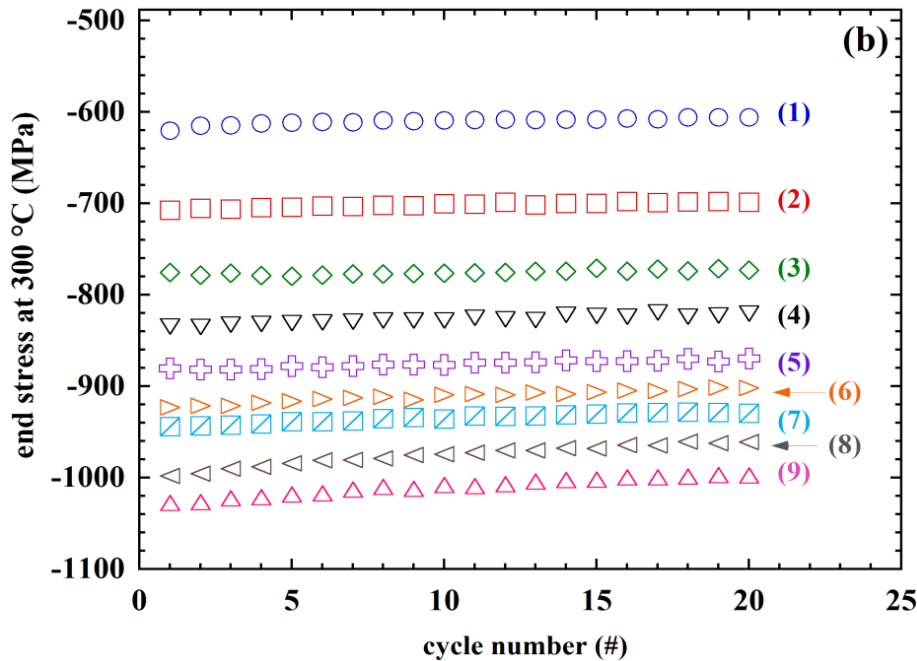
Constant-strain thermal cycling: Resultant recovery stress







Constant-strain thermal cycling: Resultant recovery stress

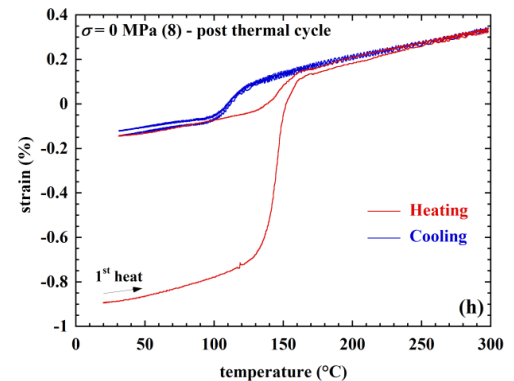
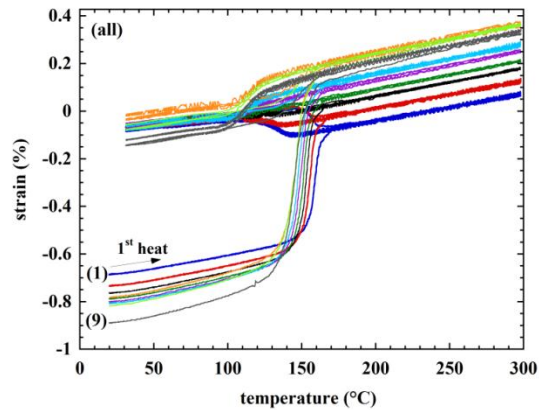
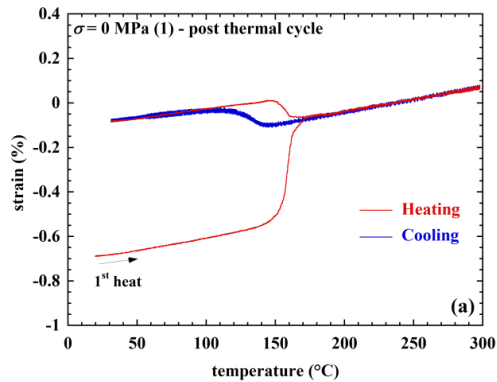


- Recovery stress increases with repeated cycles.
- Approaching 1.1 GPa





Switching from tensile to compressive B19' variants





Summary

- The recovery stresses of a precipitation strengthened, Ni-rich $\text{Ni}_{50.3}\text{Ti}_{29.7}\text{Hf}_{20}$ (at.%) high temperature shape memory alloy were evaluated in tension and compression.
- Isothermal training resulted in recovery stresses nearing 1 GPa in tension and -1.3 GPa in compression with pre-strains of 1.5 and -2%, respectively.
- Isobaric training, resulted in recovery stresses nearing 1.1 GPa in tension and -1.5 GPa in compression with training stresses of 200 and -400 MPa, respectively.
- Cycling preloading increased the stress capability
- How does it look in Torsion?